Influence of the set size and probe item affiliation in the Sternberg memory task on auditory event-related potentials

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Abstract— **The purpose of this study is to examine cerebral dynamics that occur as a result of memorizing and retrieving information from working memory. A modified Stenberg memory task was performed. We recorded auditory event-related potentials evoked by the memory task. Subjects were healthy adults with no auditory impairments. During the Sternberg experiment, sets of two or four digits were acoustically presented to subjects. After the last item in the set, the target digit (probe) was presented. Subjects had to indicate whether the probe did (positive probe) or didn't (negative probe) belong to the presented set by pressing appropriate buttons. According to the obtained results the reaction time increases with the increase of the memory set size. The activity in the period in which subjects rehearse the previously presented set is stronger expressed for the set consisted of two items. For the set of two digits the MPW appears earlier and its amplitude is greater than for the set of four digits. The amplitude of the major positive wave (MPW) is greater for the positive probe than for the negative probe, and the latency of the MPW evoked by the negative probe is greater than for the positive probe. Obtained results correspond to the presently accepted theory, but there are also interesting features for further research.**

Keywords— **Sternberg memory task, auditory event-related potentials, reaction time, set size**

I. INTRODUCTION

According to the popular model of the human memory, the dual-memory theory, there are two fundamental types of human memory, short-term memory and long-term memory. Short-term memory (STM) is a system for temporarily storing and managing information [1]. Information is only briefly stored in STM, about 10 seconds. Estimates of the capacity of short-term memory vary – from about 3 or 4 elements to about 9 elements. George A. Miller (1956), when working at Bell Laboratories, conducted experiments showing that the store of short term memory was 7±2 items, but modern estimates of the capacity of short-term memory are lower, typically on the order of 4-5 items [2]. Long-term memory is assumed to store information indefinitely, and is thought to have an indefinitely large storage capacity [3].

The original purpose of the Sternberg memory task was to study the retrieval of information from short-term memory, especially the effect of the number of elements in memory on the reaction time [4]. In typical task, a memory set of up to six items is presented on a screen, and about 3 s later, a probe item is shown and the subject has to indicate whether the probe belongs to the presented set. The reaction time increased linearly as a function of memory set size: the larger set size, the more items the subject must scan in short-term memory before a response is made [5].

Several studies have also studied event-related potentials (ERP) evoked by the Sternberg memory task. The latency of the P300 wave increased as the memory set size increased and the amplitude of the P300 was greater following probe items identified as members of the original memory set (positive probe) than probe items that weren't members of the original set (negative probe) [6]. The latency of the P300 wave is believed to index the stimulus evaluation time [7]. The latency of the P300 evoked by the Sternberg paradigm has been thought to reflect the time occupied by the memory scanning, whereas the reaction time includes an additional contribution from the subsequent response selection and execution. The increase of the P300 wave latency with the increase of the memory set size was attributed to greater amounts of time required to do more difficult memory tasks. In most studies there was a significant increase in P300 latency with an increasing memory load, but, there were also some exceptions. Some studies reported a significant effect of the set size on the amplitude, but not on the latency of the P300 wave [8].

The Sternberg memory task is usually associated with visual event-related potentials and in that case, the major positive component of the event-related potentials is mostly the P300 wave. That is the reason why most of the studies analyze the latency and the amplitude of the P300 wave related to the memory set size and the affiliation of the probe item. In the case of auditory event-related potentials, the subject needs longer time to recognize the stimulus, so there could not be the P300 wave like component of event-related potentials. The major positive wave (MPW)

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appears later than the P300 wave should appear, but it has the same features like the P300 wave.

II. Materials and methods

In order to examine cerebral dynamics that occur as a result of memorizing and retrieving information from working memory, a modified Stenberg task was performed. Subjects were instructed to memorize a set of digits that consisted of two (Set2) or four digits (Set4). After each set of digits a target digit (probe) was presented. A subject had to decide whether the probe did (positive probe) or did not belong (negative probe) to the presented set.

Subjects that participated in the experiment were 9 males and 4 females. They ranged in age from 20 to 24 years (mean 23.38 +/- 1.19). Subjects did not suffer from any known neurological or other illness. They were all right handed. After the experiment was explained to them in details, all subjects signed an informed consent form.

In the experiment a set of digits was presented to a subject using an earphones set. The beginning of the set was announced by a warning signal (1000 Hz tone). The presentation of each digit lasted for 1.2 s. After the set presentation, there was a 3 s pause after which the probe was presented. From subject's response till the beginning of the next set, there was a 4 s pause. The subject had 2 s, starting from the beginning of the probe presentation, to make a decision whether the probe matched one of the digits in the presented set. Sets of two and four digits appeared randomly in equal ratio. There were 50 sets which consisted of two digits and 50 sets which consisted of four digits. The experiment lasted for 20 min and in order to minimize a subject's fatigue and to keep the subject's awareness and attention, there was an arbitrarily break in the middle of the experiment for the subject to rest.

During the experiment subjects were instructed to minimize blinking and body and ocular movements as much as possible. Subject's eyes were kept opened during the experiment in order to minimize the alpha rhythm. The subject had to react as fast as possible after the probe presentation. The response was made using a small numeric keyboard. Two keys were used to obtain the response; the subject pressed one appropriate key with his/her left thumb when the probe matched one of the digits in the set, otherwise the subject pressed another key with his/her right thumb. A reaction time was calculated as a period from the moment the probe presentation started till the moment in which the appropriate key was pressed.

Stimuli were generated by E-Prime software (Psychology Software Tools, Inc.). Event-related potentials (ERP) were recorded using a 32 channel EEG device. As a recording device, Brain Products amplifier QuickAmp136 with electrode-cap actiCAP was used. The Brain Vision Recorder and Analyzer software of the same manufacturer were used.

ActiCAP with its active electrode system enables low electrode-skin impedances and fast electrode placement. The electrode impedance of less than 5 kOhm was adjusted using an electrically high conductive gel. Electrodes were placed according to the International 10/10 system. The monopolar recording was performed toward linked mastoids as a reference electrode. EEG signals were filtered with a pass band filter with a low-cutoff frequency set to 0.1 Hz and a high-cutoff frequency set to 70 Hz. All signals were digitalized by a sample rate frequency of 1000 Hz. Two bipolar channels (HEOG, VEOG) were used for the horizontal and vertical eye movements monitoring. Trigger signals were sent to the amplifier by the E-Prime software. During the whole experiment continuous EEG, VEOG, HEOG and trigger signals where recorded.

The ERP analysis was performed off-line after each experiment. Two different periods were analyzed. The first analyzed period was the period between the set and the probe presentation. The analyzed time interval was 200 ms before and 3000 ms after the trigger onset. The ERP baseline was determined as the average of all samples from the first 200 ms period. The second analyzed period was the period of the probe presentation and the subject's response. The analyzed time interval was 500 ms before and 1800 ms after the trigger onset. The ERP baseline was determined as the average of all samples from the first 500 ms period. Before each signal averaging, the computerized semiautomatic ocular correction and artifact rejection was made in order to reject trials in which blinks, artifacts or deviations in the eye position occurred. From the individual ERPs the grand average was computed. Then the trails were filtered by a low pass filter with a cutoff frequency of 8 Hz in order to eliminate the unwanted alpha activity.

III. Results

Obtained results are shown in the form of maps of spatiotemporal distribution and in the form of wave signals.

Spatiotemporal distributions of ERP signals evoked in the period between the end of the presented set and the probe onset are presented on Figure 1 and Figure 2. With presented maps different kinds of brain dynamics are clearly indicated.

Duration of the presented period is 3000 ms and in that period subjects rehearse the previously presented set stored in the short-term memory. The main activity in that period is the positive activity in the frontocentral region. This activity is increased for ERP signals evoked after the end of the Set2 which are shown on Figure 1.

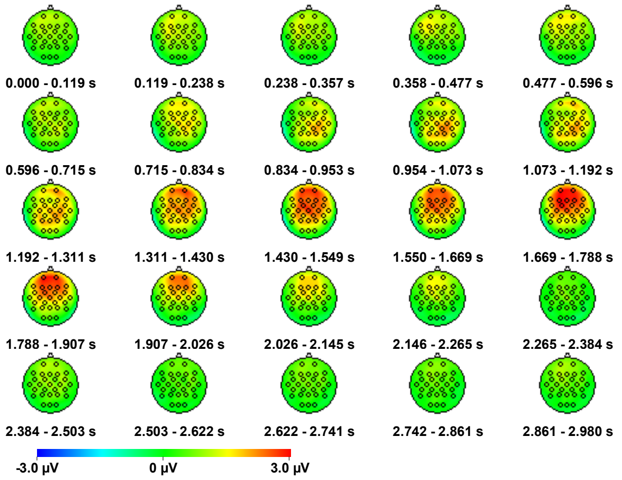

Fig. 1 Spatiotemporal distribution of ERP signals evoked in the period between the end of the Set2 and the probe onset; 0 ms to 2980 ms

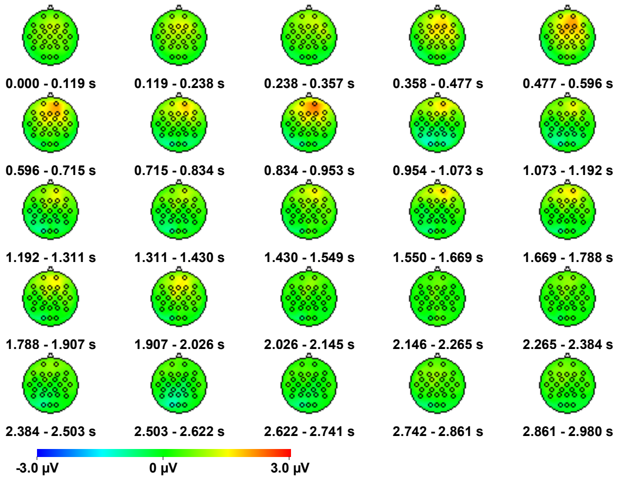

Fig. 2 Spatiotemporal distribution of ERP signals evoked in the period between the end of the Set4 and the probe onset; 0 ms to 2980 ms

Spatiotemporal distributions of ERP's for Set2 and Set4 are displayed on Figure 3 and Figure 4 in the form of maps.

On both figures the negative activity in the frontal region is clearly visible, especially in the time interval from 290 ms to 570 ms after the probe onset. This negative activity is increased for the Set2. The most significant activity visible on both figures is the positive activity in the parietal region, the major positive wave (MPW). The MPW occurs from 600 ms to 1290 ms after the probe onset. This activity is increased and starts earlier for the Set2 than for the Set4.

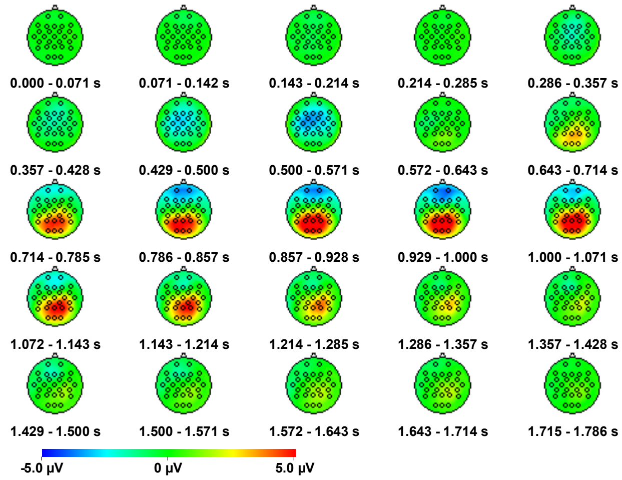

Fig. 3 Spatiotemporal distribution of ERP signals evoked by all positive probes for Set2; from 0 ms to 1786 ms

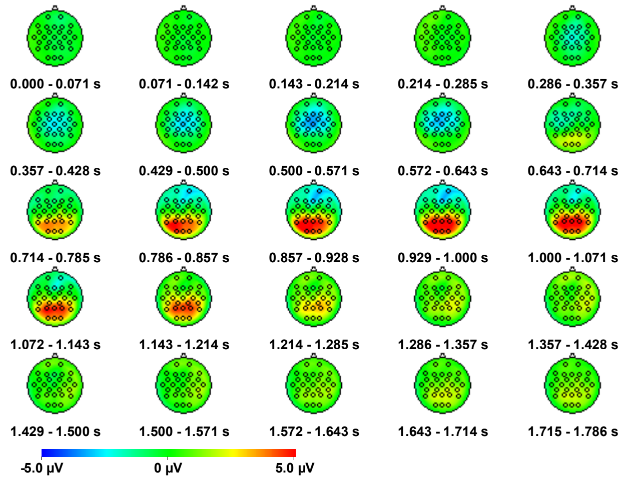

Fig. 4 Spatiotemporal distribution of ERP signals evoked by all positive probes for Set4; from 0 ms to 1786 ms

On Figure 5 are displayed obtained event-related potentials. The full line represents ERP signals evoked by positive probes and the dashed line represents ERP signals evoked by negative probes for the Set2. The time interval of 500 ms before and 1800 ms after the probe onset is shown. From the figure is obvious that the amplitude of the MPW evoked by the positive probe is greater than the amplitude of the MPW evoked by the negative probe, but the latency of the MPW evoked by the negative probe is greater than for the positive probe. The maximum positive peek for the MPW evoked by the positive probe is 6.47 µV (PP) and for the MPW evoked by the negative probe is 4.650 µV (NP). The latency of the MPW evoked by the negative probe is

670 ms and the latency of the MPW evoked by the positive probe is 570 ms. For the Set4, these differences are less prominent.

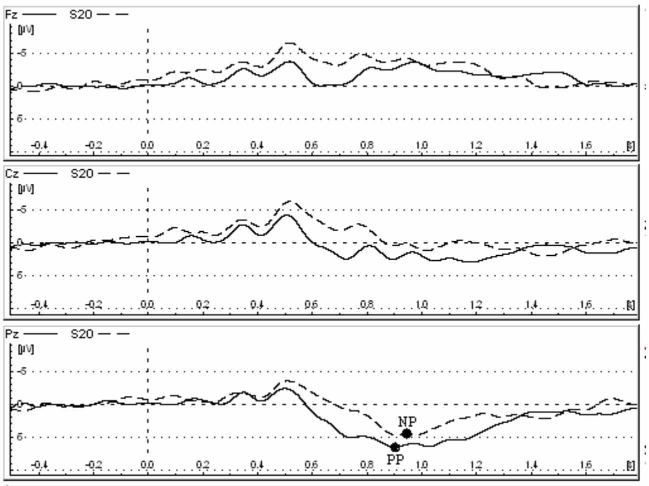

Fig. 5 ERP signals evoked by all positive probes (full line) and by all negative probes (dashed line) for sets consisted of two digits

The reaction time for positive probes for the Set2 is 1125 ms +/-125 ms and it is shorter than the reaction time for positive probes for the Set4, which amounts 1203 ms +/-120 ms. The reaction time for negative probes (1158 ms +/-114 ms) is greater than the reaction time for positive probes (1125 ms +/- 125 ms) for the set of two items, but for the set of four items the reaction time for positive probes (1203 ms +/- 120 ms) is greater than the reaction time for negative probes (1176 ms +/-102 ms).

IV. Discusion

According to obtained results, it is visible that there is an influence of the memory set size and the probe item affiliation on event-related potentials and the reaction time. The reaction time increases with the increase of the memory set size, which is in accordance with the presently accepted theory. The greater reaction time for the positive probe than for the negative probe for the set of four digits supports the Sternberg's theory that the memory scanning process is exhaustive: even when a match has occurred, scanning continues through the entire series [4].

The amplitude of the MPW is greater for the positive probe than for the negative probe and the latency of the MPW evoked by the negative probe is greater than for the positive probe which follows the presently accepted theory.

According to differences between the MPW evoked by probes for the set of two digits and by probes for the set of four digits, the MPW appears earlier and its amplitude is increased for the set of two digits. It was expected that the MPW for the set of two digits would appear earlier, but is questionable why the amplitude of the MPW for the set of two digits is increased.

The activity in the period in which subjects rehearse the previously presented set is stronger expressed for the set consisted of two items. It can be explained that because of the smaller size of the set, the subject's frequency of the rehearsal is higher and this entails the increased activity. Also, because of uncertainty if the current set is the set of two or four elements, the expectation of the possible appearance of the next two elements takes place.

V. Conclusions

The results confirm that the set size and the probe affiliation to the set have the influence on the event-related potentials and the associated reaction time. The reaction time results matched the presently accepted theory. The results associated with event-related potentials also corresponded to the presently accepted theory, but as well showed some new features interesting for the future research.

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